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Preface

This report is a quarterly summary of the research activities by the Jet Propulsion Laboratory, in the field of nondestructive testing of solid-propellant rocket motors. Section I details the progress in specific areas of research; Section II presents a continuing technical literature search of the subject. An introduction to the problems and objectives of the program was given in *QSR 38-1*.

The work reported herein is undertaken in partial fulfillment of the Advanced Research Projects Agency Letter Order No. 107-60, for the National Aeronautics and Space Administration.

W. H. Pickering, *Director*
Jet Propulsion Laboratory

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I. Physical Properties Studies

A. Viscoelastic Strain Analysis by Photoelastic Coating Technique

The prediction of when and where the probable failure of a propellant grain is to occur is usually based on engineering hypotheses. The bases for these hypotheses are usually chosen so as to make theoretical solutions feasible. The object of this study is to present an engineering technique that will enable the investigator to formulate correct hypotheses with regard to propellant grain stress analysis. The general propellant to be analyzed may justifiably be considered to be of a nonlinear viscoelastic nature, at least for environmental loadings near design failure.

Due to the inherent difficulties involved with nonlinear mechanics, the stress engineer is not equipped to solve the general stress–strain problem; he must know what the deformations of a material are for any loading before a general analysis can be developed. While an infinite array of strain gages would solve any stress problem, the strain measuring devices that normally are available, if applicable, can at best only represent isolated average strain readings. The technique under investigation enables the engineer to determine the boundary condition versus strain relationships for at least the two-dimensional case.

1. Basic Principle

The theory of the photoelastic coating technique is derived from classical photoelasticity (Refs 1, 2, and 3), which is based on an experimentally observed stress–optic rule. The rule states that the relative retardations of normally polarized light, as it passes through a birefringent material, is proportional to the thickness of the birefringent material and to the difference of principal stresses (Ref 1).

$$\delta_1 - \delta_2 = Ct(\sigma_1 - \sigma_2) \tag{1}$$

where

$\delta_1 - \delta_2$ = relative retardation of light in wavelengths (λ)

C = stress–optic constant

$\sigma_1 - \sigma_2$ = principal stresses difference, $\sigma_1 > \sigma_2$

t = thickness

In classical photoelasticity, a birefringent transparent plastic model is studied for its stress–strain relationships; this model is usually a two-dimensional structural analog. Strain response of the model is assumed to be that which the structure would undergo under identical loading. The disadvantage of this method is that the strain distribution exhibited by the model is not necessarily that which the structure would experience. This is because of the inherent differences of the materials under consideration.

The photoelastic coating technique has existed for some time (Refs 4, 5, 6, and 7), and is analogous to the classical method. Its application to propellant work has been made feasible by the development of low-elastic-modulus (500 lb/in^2 or less), linear stress–optic, birefringent coating materials.

The linear model (coating) is bonded to the nonlinear structure. Upon stressing the nonlinear structure, the

structural strains are transmitted to the linear model. The strains in the linear model are measured by the same techniques available to the classical method. The relative polarized light is retarded twice as much for the transparent–reflective bonded model than for the classical transparent model. Therefore, the equation governing the coating method is

$$\delta_1 - \delta_2 = 2Ct(\sigma_1 - \sigma_2) \qquad (2)$$

2. Mechanical-Optical System

a. Components. The mechanical–optical system used for this study is a crossed polariscope (Figs 1 and 2). Essentially, this system consists of a light source and two polarizers (Fig 3), two $\lambda/4$ birefringent plates, the model under investigation (Fig 4), and a camera.

Natural light is plane polarized as it passes through the first polarizer. The first $\lambda/4$ plate transforms this plane polarized light to circularly polarized light, which then enters the birefringent coating, is reflected at the coating-structure interface, passes through the second $\lambda/4$ plate, and finally transmits through the second polarizer (analyzer) to the camera.

b. Operational analysis. If white light is used as a source and the structure is loaded, the observer (camera) will see through the analyzer a repeating color spectrum over the entire surface area of the birefringent model. Each repetitive cycle (fringe) represents a linear increase in differences of principal stresses as indicated by Equation 2. Any specific colored curve describes a region in which the difference in magnitude of principal stresses is constant. These lines are called *isochromatics*.

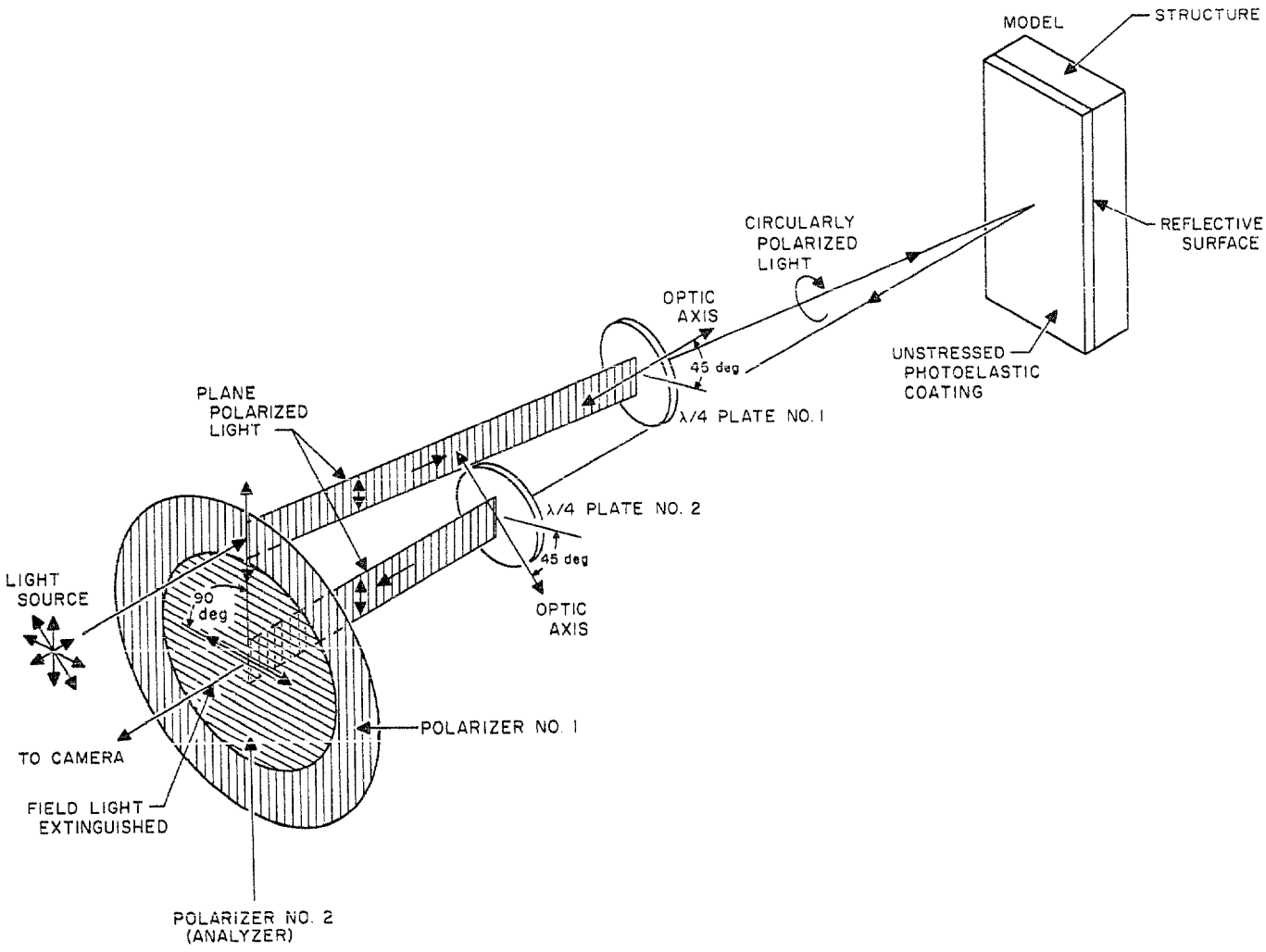


Figure 1. Crossed polariscope system

Should monochromatic light be used and the two $\lambda/4$ plates removed, repeating fringes of only one color (that of the monochromatic source) would be observed. Superimposed on these curves are other curves of extinguished light. These "black" curves are called *isoclinics* and have the property of mapping out regions where the directions of principal stresses are the same. By rotating the polarizer–analyzer, the entire directional map associated with the stresses may be plotted.

Thus, one map indicates the magnitude of difference in principal stresses for any given loading condition (isochromatics), and another map, which may be superimposed, indicates the directions of the principal stresses (isoclinics).

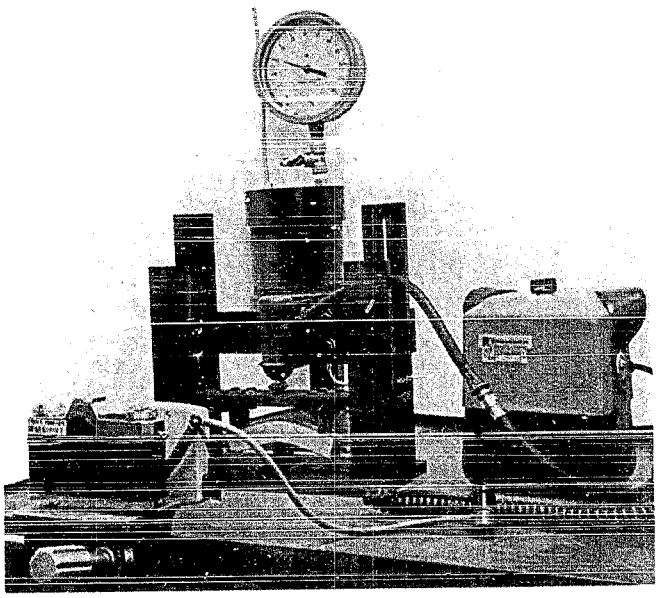


Figure 2. Polariscope and hydraulic–pneumatic three-point loading system

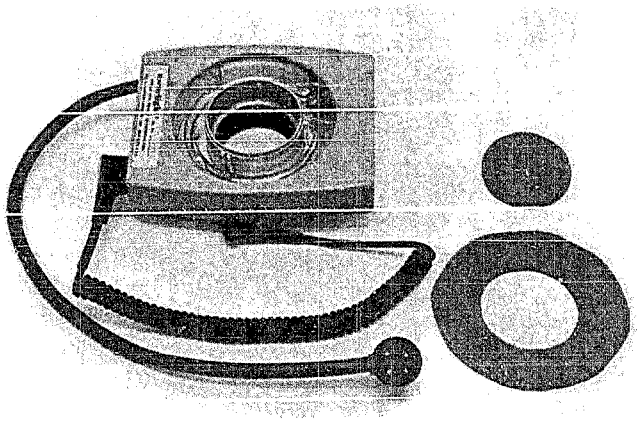


Figure 3. Polariscope attachment for camera

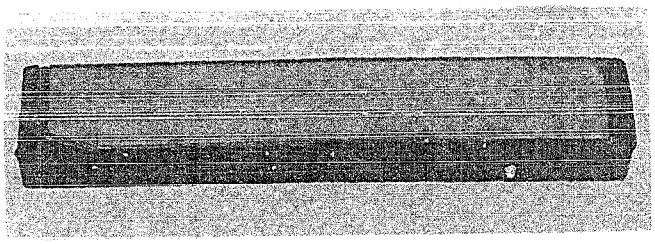


Figure 4. Coated inert propellant

The two $\lambda/4$ birefringent plates are used for the detailed isochromatic studies in order to effectively remove the superimposed isoclinics; the plates introduce circularly polarized light to the test model (Fig 1). (If a monochromatic light source is used with the plates, extinction of the isoclinics is complete. It also is to be noted that special cases exist where the isoclinics will remain even with the insertion of $\lambda/4$ plates.)

c. Separation of principal stresses. To separate the principal stresses, the investigator must introduce a second equation to solve for the second unknown. This may be done by applying the equilibrium equation to properly chosen cuts through the model. By noting the boundary conditions, the principal stresses may be graphically reduced by a method suggested by A. Kuske (Ref 8). It should be noted that other methods may be used to separate the principal stresses.

3. Calibration of Birefringent Coating Material

a. Optical fringe–strain correlation. The experimental optical fringe–strain curve is shown in Figure 5. For a static loading at room temperature, no appreciable relaxation was observed for a period of 10 minutes and a load intensity of 4 fringes. Any relaxation strains would be fully recovered within 1 hour. No parasitic birefringence was observed for the limited types of tests to which the material was subjected.

b. Determination of optic constant. The optic constant C in Equation 2 was obtained by taking a rectangular sample of the coating material and subjecting it to a tensile test. By applying a relatively uniform tensile stress, $\sigma_1 = P$, $\sigma_2 = 0$, a stress–birefringent relationship was observed. Average longitudinal and lateral strains were measured by studying displacements using a photographic technique (Fig 6).

The different parameters were plotted as shown in Figure 7. Of importance are the strain–retardation,

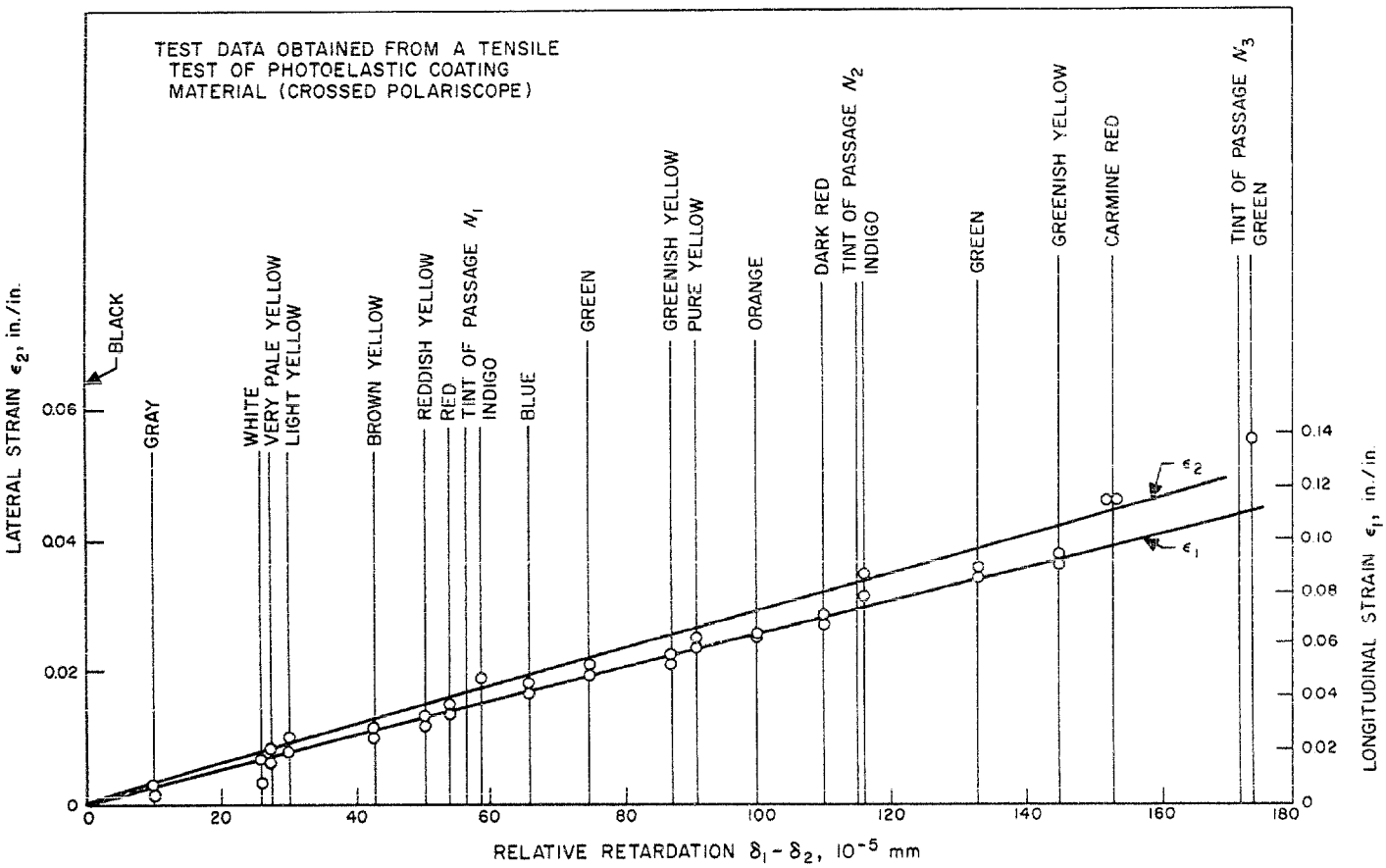


Figure 5. Optical fringe–strain relationship

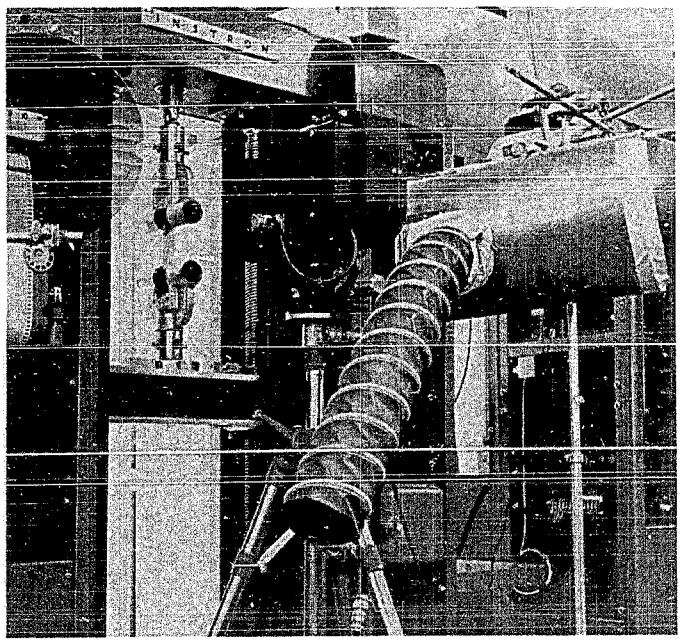


Figure 6. Photographic equipment used in optic-constant determination

and the stress–strain curves. C is evaluated from the data presented in this figure and is found to have a value of 0.512×10^{-5} lb/in.^{2}; the modulus of the material, E, is approximately 530 lb/in.^{2}; and the average Poisson's ratio based on Cauchy strains is found to be about 0.43.

Defining the strain–optic constant

$$K = \frac{CE}{1 + \nu}$$

where ν is Poisson's ratio, Equation 2 may be transformed to relate the relative retardation to the difference in magnitude of the principal strains

$$\delta_1 - \delta_2 = 2Kt(\epsilon_1 - \epsilon_2) \tag{3}$$

This relationship is based on the assumption that the principal strains coincide with the direction of the principal stresses, and that the modulus and Poisson's ratio remain constant.

The optic-constant calibration is based on the stress–optic relationship (Equation 2) insofar as the principal

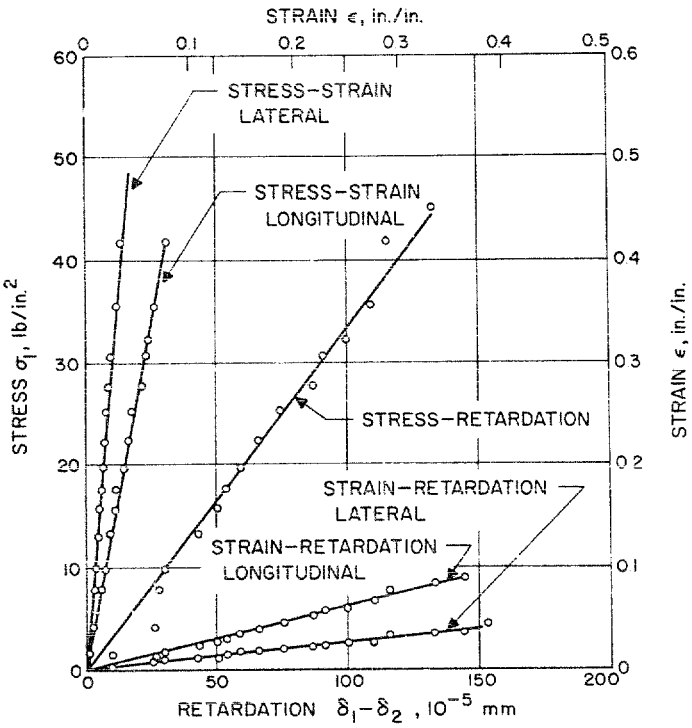


Figure 7. Properties of coating material

strains cannot be measured precisely. However, the strain–optic relationship (Equation 3) is applicable to the coating because the strain–fringe and the stress–strain relationships are shown to be linear (Fig 8). K is found to have a value of 0.0019. Table 1 summarizes the correlation between principal stress and relative retardation.

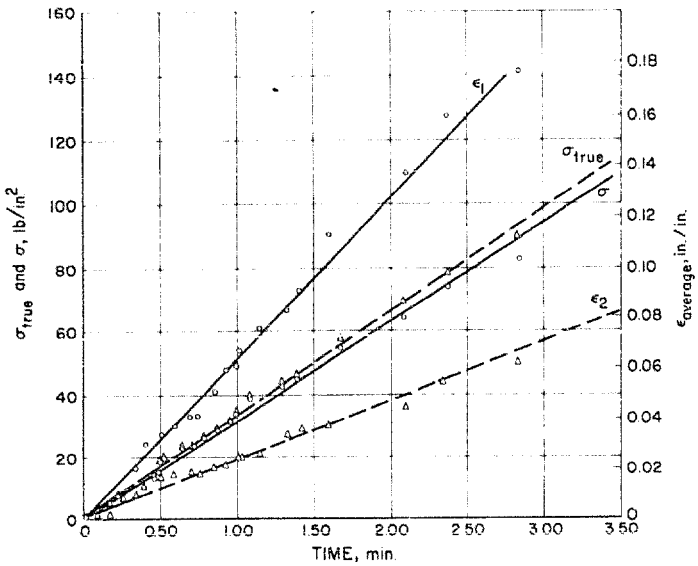


Figure 8. Stress–strain–fringe relationships

4. Strain Analysis Procedure

To illustrate the applicability of the photoelastic coating method to the basic study of propellant stress analysis, a simple beam of inert propellant (whose physical properties are similar to those of an operational propellant) was studied; the birefringent coating was bonded to the surface of this structure.

This specimen was subjected to a symmetrical three-point load applied by means of the hydraulic–pneumatic system (Fig 2). Figure 9 shows the loading system, the shear diagram, and the moment distribution. The polariscope was used to obtain the photoelastic data (Fig 10) which was in turn reduced by graphical superposition to Figure 11. The isochromatic fringe values correspond to those values shown in Table 1.

After the isoclinics and isochromatics had been plotted, the principal stresses were separated graphically. The method used to separate the stresses was that suggested by A. Kuske; this method was chosen because of its relative simplicity.

A section of the beam surface (A-A) was arbitrarily chosen to be examined for strain distributions. The assumption was made that the stress–optic properties of the photoelastic coating are the same in compression as in tension. The assumption is valid for this system.

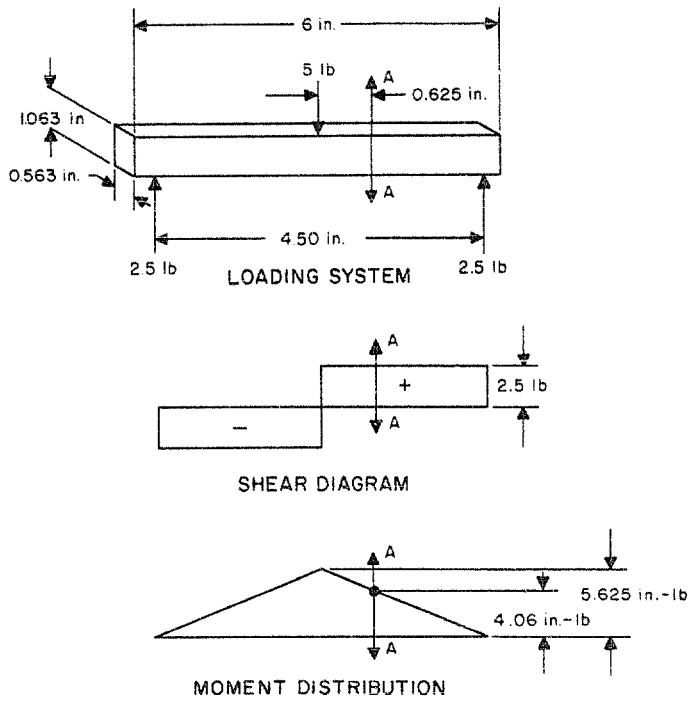
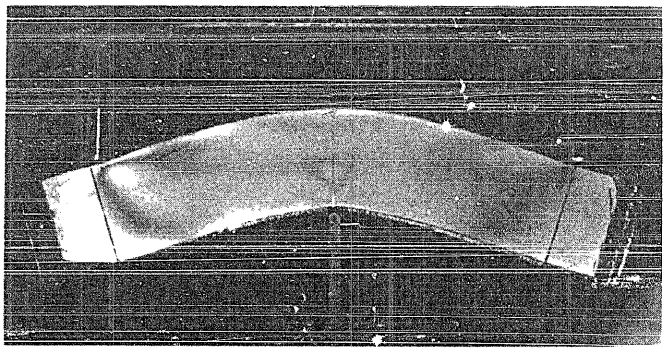
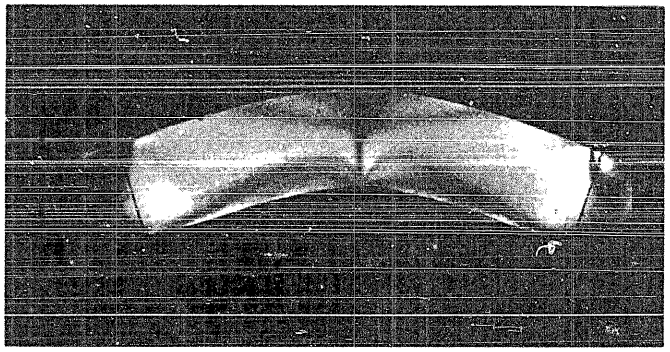


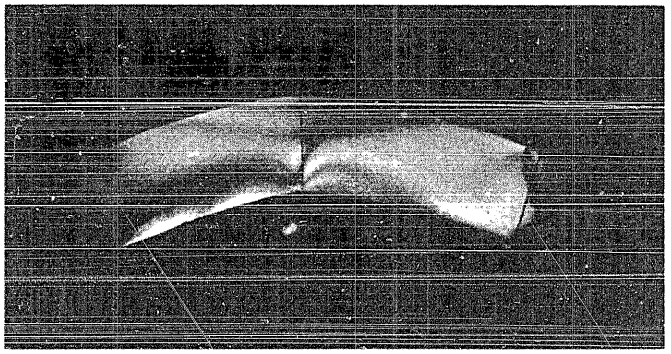
Figure 9. Physical loading specifications



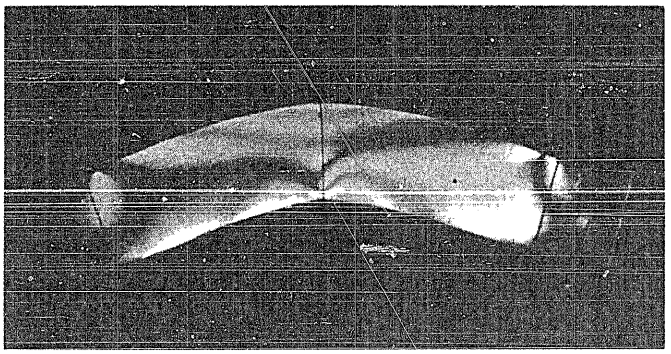
(a) λ/4 PLATES IN PARALLEL POLARISCOPE



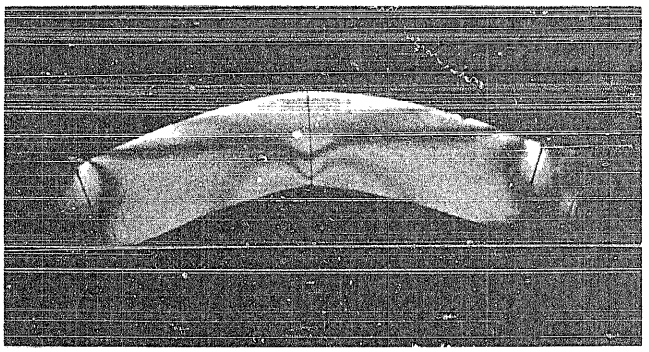
(b) 0 DEGREE



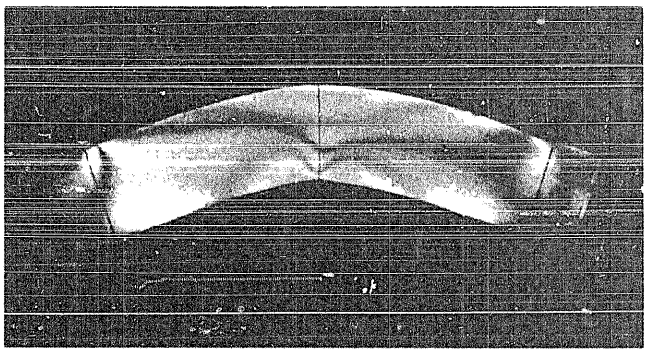
(c) 15 DEGREE



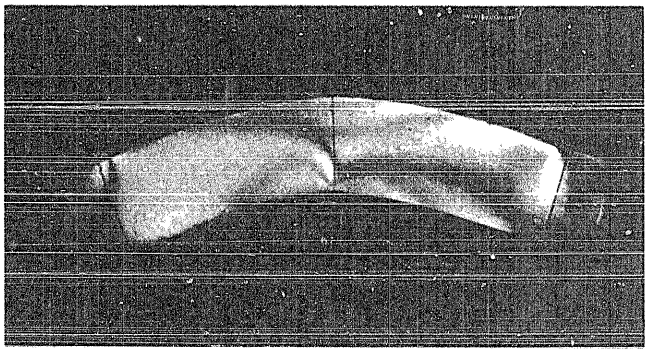
(d) 30 DEGREE



(e) 45 DEGREE



(f) 60 DEGREE



(g) 75 DEGREE

NOTE: (1) WHITE LIGHT SOURCE USED
(2)(b) THROUGH (g): CROSSED POLARISCOPE; REFERENCE ANGLE

Figure 10. Photographic data

Table 1. Optical properties of coating material

Color		True principal stress $(\sigma_1 - \sigma_2, \sigma_2 = 0)$, lb/in.^{2}	Relative retardation $(\delta_1 - \delta_2)$, 10^{-5} mm	Fringe value $\left(\frac{\delta_1 - \delta_2}{57.5}\right)$
Crossed system	Parallel system			
Black	White	0	0	0
Gray	Yellowish-white	1.7	10.0	0.18
White	Light red	4.5	26.0	0.45
Very pale yellow	Dark red brown	8.0	27.5	0.48
—	Tint of Passage N_1	—	28.7	0.50
Light-yellow	Indigo	10.3	30.0	0.52
Brown-yellow	Gray blue	13.3	43.0	0.75
Reddish-orange	Bluish green	16.0	50.5	0.88
Red	Pale green	17.9	54.0	0.93
Tint of passage N_1	—	19.4	57.5	1.00
Indigo	Gold Yellow	20.1	59.0	1.03
Blue	Orange	22.8	66.0	1.14
Green	Red	25.5	75.0	1.30
—	Tint of passage N_2	—	86.2	1.50
Greenish-yellow	Violet	28.0	87.0	1.52
Pure yellow	Indigo	30.9	91.0	1.60
Orange	Greenish-blue	32.5	100.0	1.74
Dark red	Green	35.9	110.0	1.92
Tint of passage N_2	—	38.9	115.0	2.00
Indigo	Gray yellow	42.1	116.0	2.02
Green	Brown red	45.2	133.0	2.32
—	Tint of passage N_3	—	143.7	2.50
Greenish-yellow	Grayish indigo	48.4	145.0	2.52
Carmen red	Green	59.0	153.0	2.57
Tint of passage N_3	—	60.7	172.0	3.00

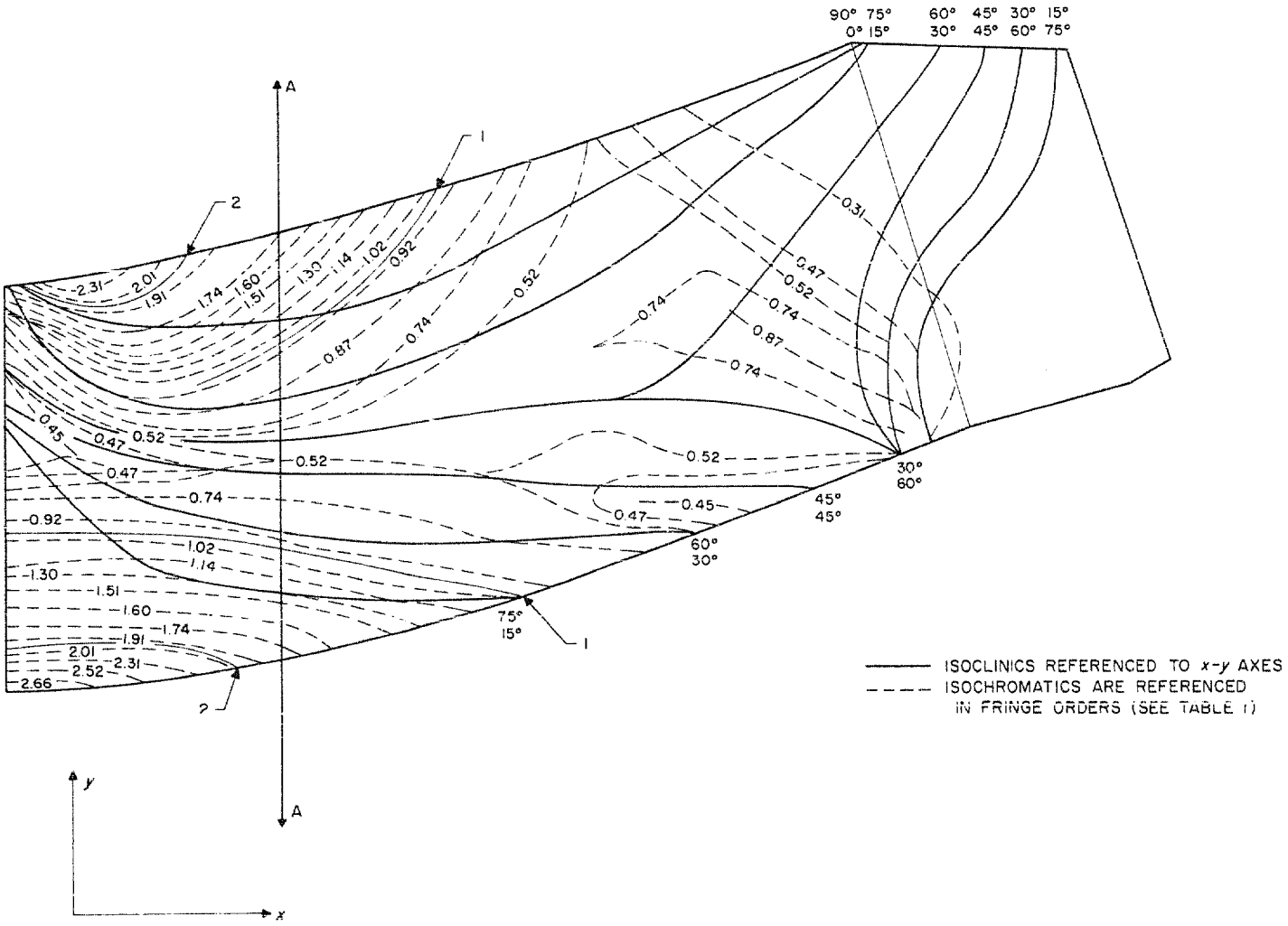


Figure 11. Isoclinic–isochromatic plot

Of considerable aid in the separation of principal stresses was Figure 12. This is a nomograph relating shear stress, principal stresses, normal stresses associated with shear stress, for any relative direction. Figure 13 is self-explanatory and demonstrates the graphical procedure employed to separate the stresses in the coating. Figure 14 compares the photoelastic measurements in the coating to the theoretical stress distribution in the propellant. Since the coating is elastic, the strains that the propellant undergoes at the surface can be determined from Table 1.

5. Conclusion

The photoelastic coating technique enables the investigator to study strain distributions on the surface of a propellant for any changing boundary condition. With this information, the general stress-distribution problem can be studied by use of the semi-inverse method of solution. By postulating the components of stress or strain and making use of the equilibrium and compatability conditions, a general solution is possible. It is also noted that the invariant functions, if applicable to the propellant, may also be determined by this method.

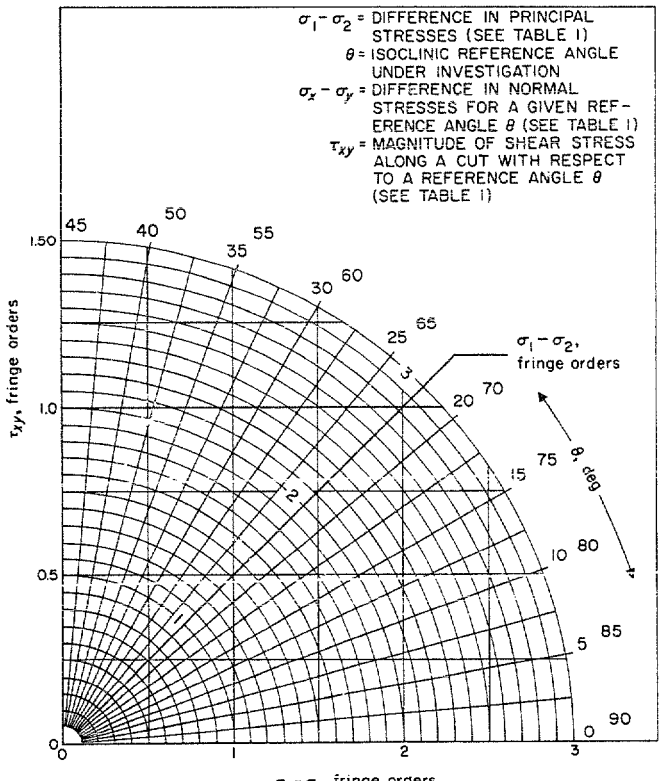

$\sigma_1 - \sigma_2$ = DIFFERENCE IN PRINCIPAL STRESSES (SEE TABLE I)
θ = ISOCLINIC REFERENCE ANGLE UNDER INVESTIGATION
$\sigma_x - \sigma_y$ = DIFFERENCE IN NORMAL STRESSES FOR A GIVEN REFERENCE ANGLE θ (SEE TABLE I)
τ_{xy} = MAGNITUDE OF SHEAR STRESS ALONG A CUT WITH RESPECT TO A REFERENCE ANGLE θ (SEE TABLE I)
τ_{xy}, fringe orders
$\sigma_x - \sigma_y$, fringe orders
$\sigma_1 - \sigma_2$, fringe orders
θ, deg

Figure 12. Nomograph used to evaluate for constant τ_{xy}

The applicability of photoelastic coating technique for the determination of propellant deformation is demonstrated by comparison with standard beam theory. Note that, although the beam exhibited large rigid motion and rotation, the maximum strain at Section A-A was about 7 percent. Therefore, small deformation theory is believed applicable.

In the elementary theory, the following assumptions are made:

(1) The propellant is an isotropic homogeneous material (linear).

(2) No strains occur along the neutral axis.

(3) Plane sections remain plane and normal to the neutral axis.

(4) $\sigma_x \neq 0$, $\sigma_y = \sigma_z = \tau_{xy} = \tau_{yz} = \tau_{zx} = 0$.

(5) Body forces are neglected.

(6) Boundary conditions on cylindrical surface are satisfied.

In mathematical terms, these assumptions are interpreted as:

$$\frac{\partial u}{\partial x} = -\frac{y}{R}, \qquad \frac{\partial v}{\partial y} = \frac{\partial w}{\partial z} = 0$$

$$\sigma_x = -Ee_x = -\frac{Ey}{R}$$

$$M = -\int_A y\,\sigma_x\,dA = \int_A \frac{Ey^2}{R}\,dA = \frac{EI}{R}$$

and

$$\sigma_x = -\frac{M}{I}y, \qquad \sigma_y = 0 \tag{4}$$

The derivation of the shear across the vertical surface is based on the assumptions that $\sigma_x = My/I$. By equating forces in the horizontal direction, the familiar shear equation is found to be

$$\tau_{xy} = \frac{V}{Ib}\int_{y_1}^{c} y\,dA \tag{5}$$

Figure 14 illustrates the accurate prediction of stresses using Equations 4 and 5 for the given environment. There-

fore, the above assumptions and equations govern the nature of the particular propellant at room temperature, for a loading duration of 5 minutes and a maximum strain of less than 7 percent.

Further work is planned to establish the photoelastic coating properties and the construction of a high-speed reflective polariscope before attempting to study the general nonlinear viscoelastic propellant.

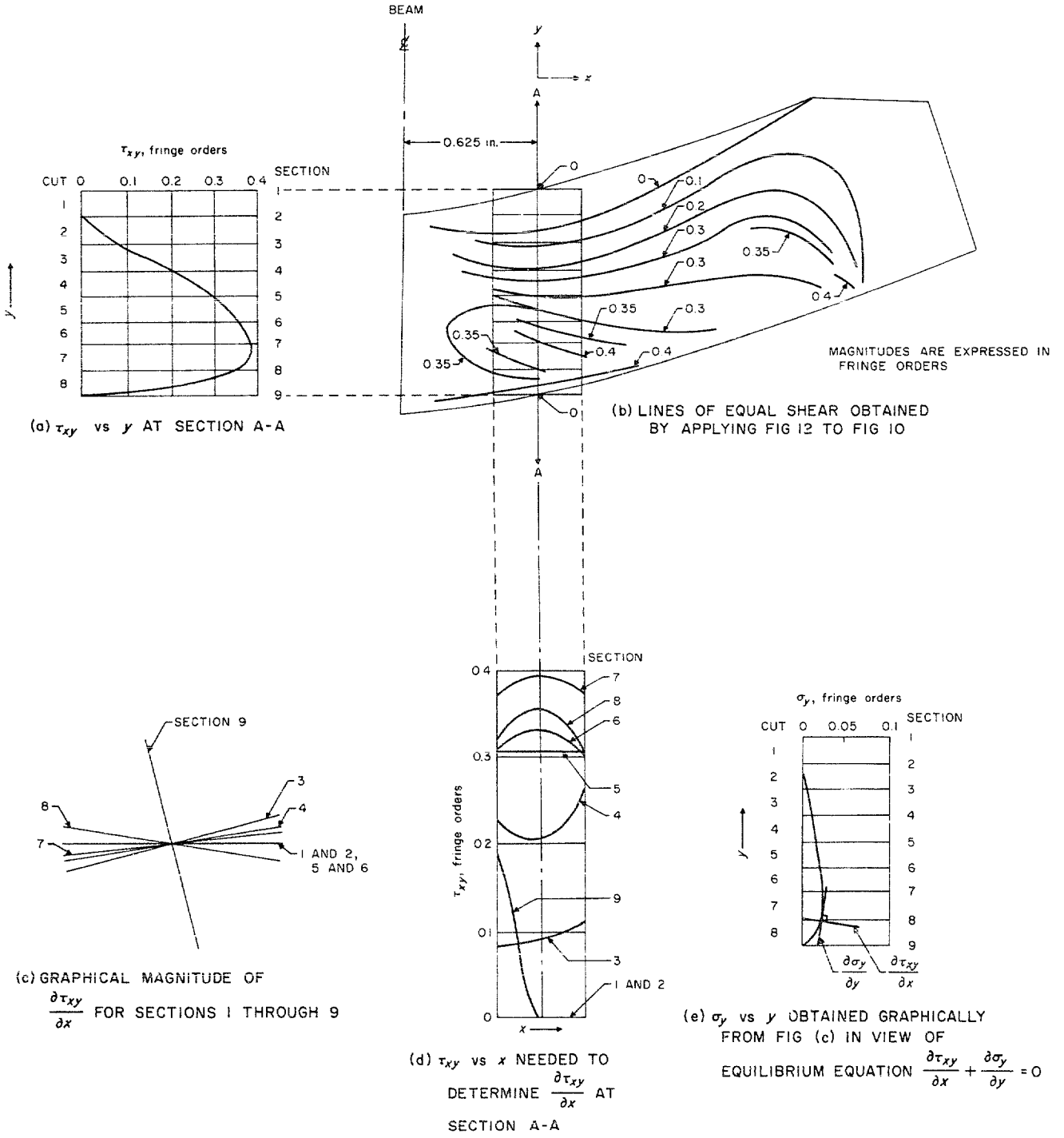

BEAM
0.625 in.
A
A
MAGNITUDES ARE EXPRESSED IN FRINGE ORDERS
(a) τ_{xy} vs y AT SECTION A-A
(b) LINES OF EQUAL SHEAR OBTAINED BY APPLYING FIG 12 TO FIG 10
SECTION 9
1 AND 2, 5 AND 6
(c) GRAPHICAL MAGNITUDE OF $\frac{\partial \tau_{xy}}{\partial x}$ FOR SECTIONS 1 THROUGH 9
(d) τ_{xy} vs x NEEDED TO DETERMINE $\frac{\partial \tau_{xy}}{\partial x}$ AT SECTION A-A
(e) σ_y vs y OBTAINED GRAPHICALLY FROM FIG (c) IN VIEW OF EQUILIBRIUM EQUATION $\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} = 0$

Figure 13. Graphical separation of shear and normal stresses

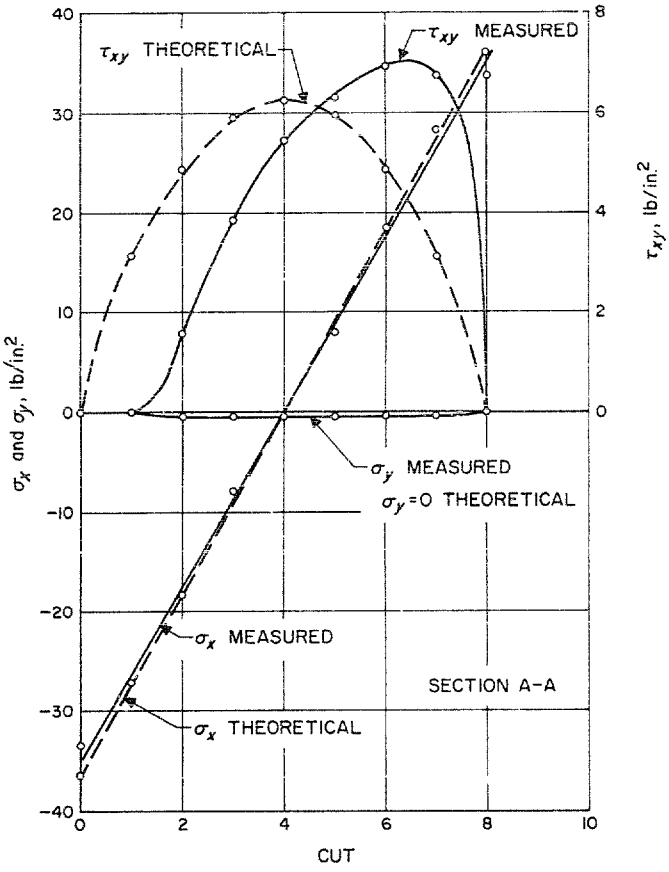


Figure 14. Comparison of photoelastic measurements and theoretical stress distribution in propellant

B. Torsion Testing

The development of a device to study the torsion of a hollow cylinder of propellant or other polymeric material has been completed. This study was consistent with the objectives of the program to study multiaxial stress states and to attempt to correlate the behavior of propellant in pure shear with the behavior noted under other stress conditions.

1. Specimen

The specimen (Fig 15) is a dumbell-shaped right-circular cylinder. The large ends are 2 inches in diameter and the smaller cylindrical section is 1.5 inches in diameter. Cylindrical web lengths of 1.8, 2.5, and 3.5 inches were used. The specimens were cast to shape in split molds using a mandrel to provide the cylindrical inner hole. The mandrel sizes varied from ½ to 1¼ inches, so that wall thicknesses of ½, ⅜, ¼, and ⅛ inch were produced in the cylindrical region. The end surfaces were milled parallel in preparation for gluing to the end adapters (Fig 15).

2. Fixtures

The test fixture (Fig 16) is fastened to the crosshead of an Instron testing machine. A steel tape, wrapped around a wheel on a shaft attached to one of the speci-

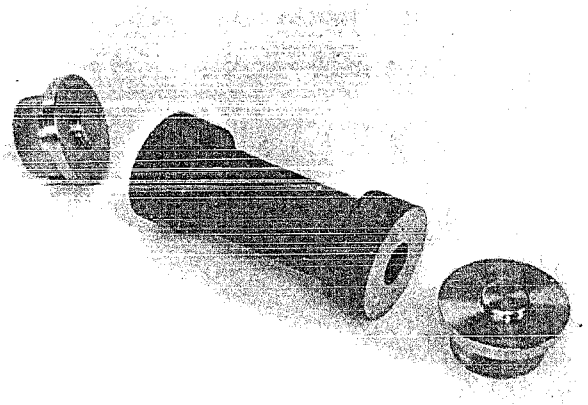


Figure 15. Propellant specimen

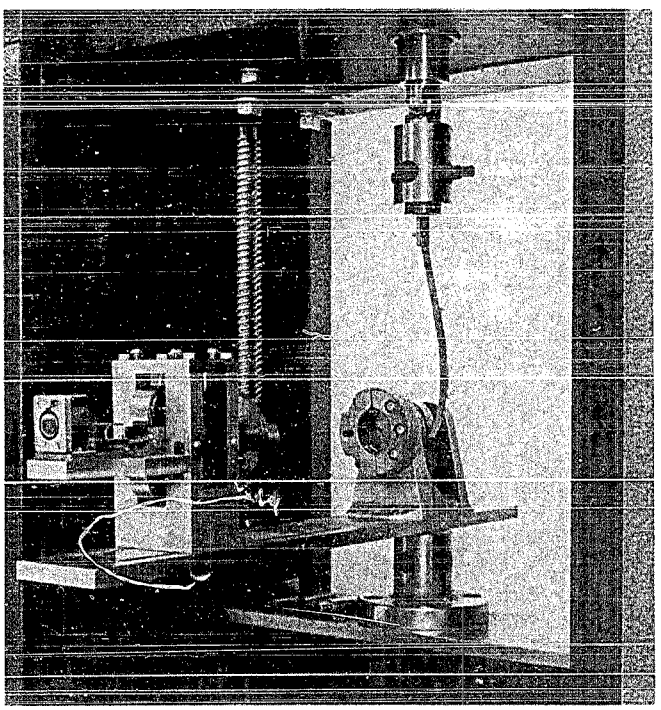


Figure 16. Test fixture

men clamps, is secured to the load cell. The rotating clamp is mounted in two ball bearings to reduce friction and eliminate wobble of the rotating end of the specimen. The other specimen clamp is mounted on ball bearings so that it will be free to move axially, but will not rotate. The amount of axial movement is monitored by a linear potentiometer.

Because of the shape of the specimen, knowing the amount of twist of the rotating end is not sufficient to define the twist in the cylindrical part of the specimen. A two-part device was designed and constructed to measure the twist directly. One part attaches directly to the specimen (Fig 17). This consists of two split rings which are fitted around the specimen and held in place by rubber bands. The inner surface of the rings is lined with rubber sheeting and the outer surface is grooved to guide an attached string.

The second part of this device (Fig 18) attaches to the test fixture itself. This piece consists of two wheels mounted on ball bearings. One wheel is fixed to the body of a rotary potentiometer, and the other wheel is attached to the shaft. The string from each ring is wrapped once around its respective wheel and hangs free with a weight tied to its end (Fig 19). A difference in rotation of the rings (clamped to the specimen) is transmitted to the wheels which drive the potentiometer. Plans for this device include development of a feedback system to the Instron such that twist rates can be programmed, and torque–twist behavior recorded.

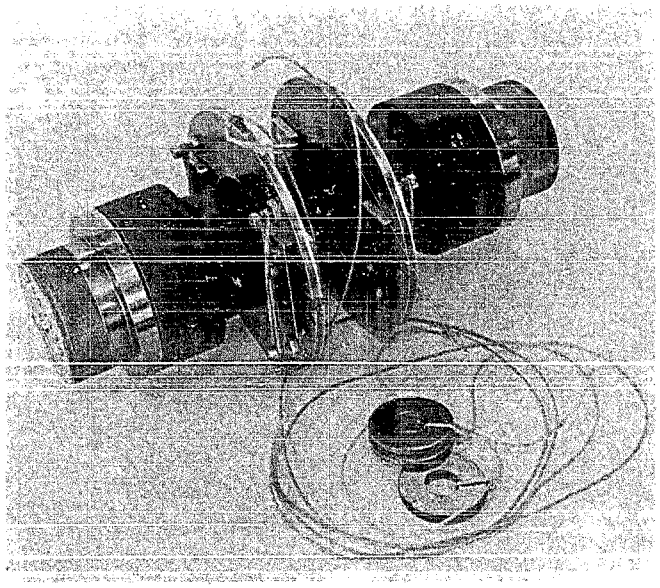


Figure 17. Twist translating rings mounted on specimen

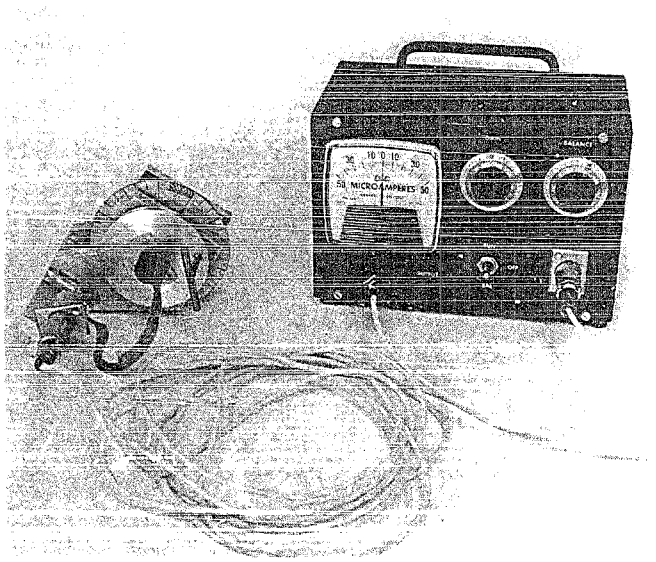


Figure 18. Twist sensing device

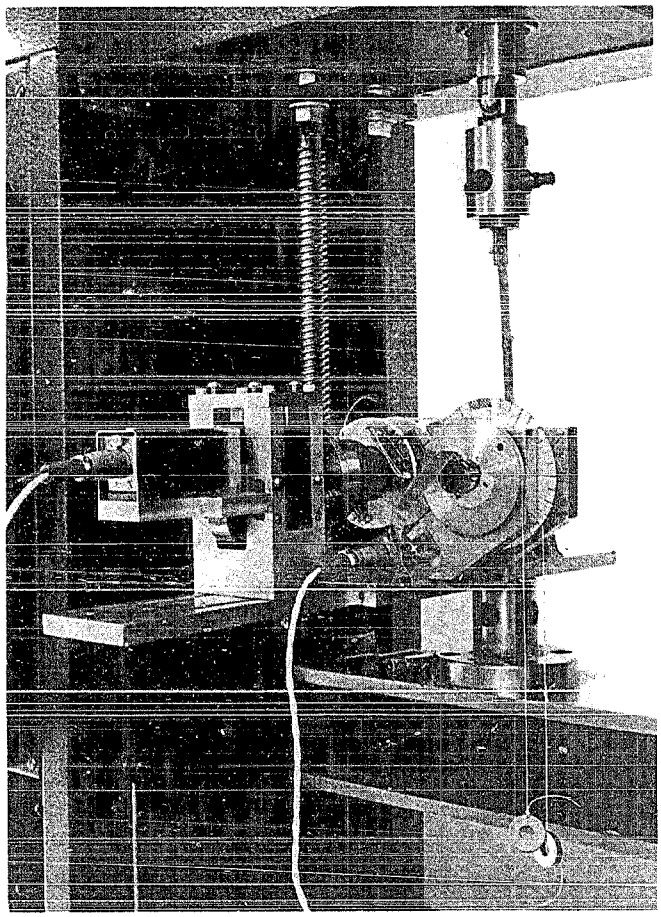


Figure 19. Twist measuring system

3. Testing Progress

Tests have begun using this equipment. The main purpose of these tests was to determine the operating characteristics of the test fixture and to establish the criteria for data analysis.

Shear stress was calculated at a location on the cylindrical web surface so as to divide the specimen into equal volumes. This "weighted-average" radius concept was considered in some detail in an earlier study (Ref 9). It was noted that maximum torque does not appear to be a consistent parameter. Depending on the specimen length and wall thickness, the decrease in torque after an apparent maximum is due to either buckling or the onset of rupture. As yet it is not possible to predict which of these phenomena will occur first, and it is difficult to detect the first signs of buckling. However, by careful observation of the specimen during test, and by an evaluation of the torque–time history, a determination of maximum torque can be made.

A plot of the shear stress across the weighted-average surface at maximum torque as a function of the twist rate is shown in Figure 20. Also shown is a plot of the angle of twist per unit length at maximum torque as a function of the twist rate. The range of twist rates was obtained both by using different specimen lengths and by varying the crosshead speed on the Instron. While the results are as yet inconclusive and not subject to rigorous analysis, it is believed that the feasibility of this technique has been demonstrated for observing the behavior of propellants in pure shear.

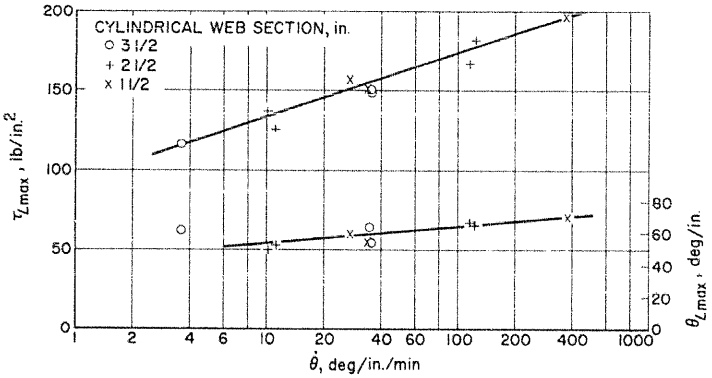


Figure 20. Shear stress, and angle-of-twist per unit length (both at maximum torque) vs twist rate

II. Bibliography

A. Radiography

SURVEY OF RADIATION TECHNIQUES
Tenney, G. H.
"Symposium on Nondestructive Tests in the Field of Nuclear Energy," (April 16–18, 1957, Chicago, Ill.)
ASTM, Philadelphia, Pa.
Special Technical Publication 223
pp. 44–61, 1958

The utilization of radiation in the field of nondestructive testing is discussed. The four kinds of radiation used in the study of physical characteristics are: X-rays, alpha particles, beta particles, and gamma rays. Sources and characteristics of these radiations are discussed. Applications in flaw detectors, liquid level indicators, wear and tear studies in the metal industry, and gages, microscopy and diffraction analyses are described.

QUARTERLY REPORT OF THE PROPULSION LABORATORY
January 1959
Army Rocket and Guided Missile Agency
Ordnance Missile Lab, Redstone Arsenal, Ala.
R-3M7N28, October 1–December 31, 1958
(CONFIDENTIAL)

The following subjects are covered: XM-3 and XM-4 squibs, igniters for *Little John* and *Honest John* rockets, plastisol nitrocellulose propellants, nitrogen fluoride chemistry, boron propellants, fluoro-polymer investigations, X-ray fluorescence analyses of aged polysulfide ammonium perchlorate propellants, chemical analysis of pyrotechnic compositions, rocket boost and exhaust investigations, hydrospinning, variable throat rocket nozzle, and use of solid propellant rocket motors as the prime mover for auxiliary power units.

NONDESTRUCTIVE TESTING OF "ROUND ROBIN" NOZZLES, *POLARIS* FIRST STAGE P/N 1-323030
Hund, F. C.
May 16, 1960
Naval Ammunition Depot, Concord, Mass.
Report QE/CO 60-AGC-37, 55 pp
SPIA File No. S60-770

The results of nondestructive testing and inspection of *Polaris* nozzles, that have induced defects, are reported. This program was conducted as part of a "round robin" by various member facilities of the JANAF Nondestructive Testing Committee to determine the most practical methods and techniques for the detection of flaws in *Polaris* nozzle components.

MANUAL OF ISOTOPE RADIOGRAPHY
Criscuolo, E. L.; Polansky, D.; Dyer, C. H.
May 23, 1960
Naval Ordnance Lab, White Oak, Md.
Serial No. SSC-121, ASTIA AD-237,536

Information and experimental data on the radiography of steel (particularly welds) using isotopes is presented. This information can assist the radiographer in choosing the proper technique for the selection of isotopes and the estimation of exposure time for a given material. The technique described can be applied to the radiographic inspection of welds contained in ship structure.

MINUTEMAN DATA BOOK FOR WEAPON SYSTEMS 133A: THIOKOL CHEMICAL CORPORATION REPORT ON XM-55 PROPULSION SYSTEM FOR INCLUSION IN WS133A DATA BOOK (U)
Giger, A. J.
July 7, 1960
Thiokol Chemical Corp., Utah Division, Brigham City
R-TU-477-7-60 AF 33(600)-36514
(CONFIDENTIAL)

Reference is made to the Thiokol specification for an X-ray method of nondestructive testing.

POLARIS POWER PLANT DEVELOPMENT
July 20, 1960
Aerojet-General Corp., Sacramento, Calif.
Report 3520-01M-33, June 1960, Under Patent Secrecy Order, (CONFIDENTIAL)
SPIA File No. S60-1027

POLARIS POWER PLANT DEVELOPMENT
August 20, 1960
Aerojet-General Corp., Sacramento, Calif.
Report 3520-01M-34, July 1960, Under Patent Secrecy Order, (CONFIDENTIAL)
SPIA File No. S60-1126

POLARIS POWER PLANT DEVELOPMENT
September 20, 1960
Aerojet-General Corp., Sacramento, Calif.
Report 3520-01M-35, August 1960, Under Patent Secrecy Order, (CONFIDENTIAL)
SPIA File No. S60-1258

POLARIS POWER PLANT DEVELOPMENT
Kirchner, W. R.
October 20, 1960
Aerojet-General Corp., Sacramento, Calif.
Report 3520-01M-36, September 1960, Under Patent Secrecy Order, (CONFIDENTIAL)
SPIA File No. S60-1445

A correlation analysis of 36 second-stage Model A1 motors was made. This analysis compares the liner and propellant inspection data with the respective motor-firing results and substantiated previous data that had indicated that *Polaris* motors could be segregated into acceptable and nonacceptable categories on the basis of liner and propellant inspection data. Two 15-KS-4000 size motors (20-in. dia) and five 3-KS-500 size motors were fired. These motors contained voids or propellant liner separations and were used to correlate inspection and firing results. All firing results generally followed the predicted curves.

Two major causes of variations in chamber pressure from motor-to-motor during first- and second-stage firings are the actual differences in propellant burning rate and the burning of propellant in areas where restriction failures have occurred. The latter condition is the more difficult to detect because restriction failures during a test cannot be monitored by conventional techniques. Therefore, a study was made to determine the feasibility of using radioactive-tracer materials to detect the location and the magnitude of restriction failures that occur during a motor test.

In this first test, 12 seeds of low-level radioactive antimony (50 microcuries/seed) were planted in the fore and aft boots of 1-PA1-196 before the motor was cast. The actual and predicted (average of previous firings) performance curves were compared. Motor pressure was from 8 to 10 percent higher than average. About 2 to 4 percent of the pressure increase can be attributed to a higher-than-average burning rate. Liquid-strand tests had indicated a burning rate of 0.307 in./sec at 1000 psia for this motor, compared wtih an average of 0.295 to 0.300 in./sec during previous tests. Special instrumentation was used to detect decreases in the radioactive count as the seeds of antimony were ejected from the motor. The time required for the propellant to recede to each radioactive particle, assuming that the fore and aft restrictions performed satisfactorily, was calculated by the use of liquid-strand data and burning-rate data from previous motor tests.

The test indicated that radioactive-tracer techniques can be used successfully to determine grain-restriction performance. The data obtained are being analyzed, and modifications will be made to improve restriction design. Further radioactive-tracer tests will be made of first- and second-stage motors.

B. Ultrasonics

APPLICATIONS OF LAMB WAVES IN ULTRASONIC TESTING

Worlton, D. C.
"Symposium on Nondestructive Tests in the Field of Nuclear Energy," (April 16–18, 1957, Chicago, Ill.)
ASTM, Philadelphia, Pa.
Special Technical Publication 223
pp 260–265, 1958

A discussion is presented of some of the potential uses of Lamb waves, and methods are suggested for practical applications. The most salient feature of the technique for testing is the ability to reveal shallow laminar defects in solid objects as well as plates. The requirement of short-time interrogating pulses is removed by eliminating the surface echo. The complexities and high frequencies of wide-band systems are thus avoided. Automatic gating is simplified so that the procedure is well suited for routine testing.

AN ULTRASONIC METHOD OF DETECTING LACK OF ADHESION BETWEEN CASE-BONDED PLASTIC PROPELLANT AND THE TUBE WALL IN ROCKET MOTORS

Lister, R.; Westcott, R. A. E.
November 1957
Royal Aircraft Establishment, Farnsborough, Great Britain
TN-R.P.D. 156 (CONFIDENTIAL)

An ultrasonic method has been developed, using only external devices, which gives clear and precise indications of defective adhesion in case-bonded rocket motors. The desired minimum size of defect can be selected and nothing smaller than this needs to be revealed. The method is amenable to automatic methods of operation and recording.

EDDY CURRENT ULTRASONIC TRANSDUCER

Libby, H. L.
August 24, 1959
General Electric Co., Hanford Atomics Products Operation, Richland, Wash.
OTS, HW-61629, 15 pp

An eddy current transducer is described which generates and detects ultrasonic vibrations in nonmagnetic metals without the use of any coupling medium between the transducer and the metal, except free space. The device is useful in measurement of metal sheet thickness and in measurement of ultrasonic transmission properties of materials.

DEVELOPMENT AND EVALUATION OF NONDESTRUCTIVE TECHNIQUES FOR ANALYSIS OF SOLID FUEL ROCKETS

Kleint, R. E.; McKown, R. D.
October 15, 1959
Ultrasonic Research Lab, Western Reserve University, Cleveland, Ohio
Progress Report 2, August 1–October 1, 1959, 11 pp SPIA File No. 1074, AF 33(616)-6603

The purpose of the work in progress is to develop ultrasonic flaw detection techniques which can be used to determine the physical integrity of solid-propellant rocket-motor case, liner, and propellant combinations. The project encompasses such problems as determining the degree and quality of the bond between the motor container and liner, and between the liner and propellant; and also detecting faults in the solid propellant grains such as cracks, voids, soft spots, and related defects. Experience has indicated that these are the most common physical defects causing improper combustion rates, loss of unburned propellant, or explosion.

The project is to be accomplished in two phases totaling 12 months. Phase I is being devoted to sample preparation, equipment procurement, preliminary tests, and the development of special piezoelectric transducers capable of high efficiency energy conversion. Phase II will consist of utilizing the equipment and techniques from Phase I on detailed tests of case, liner, and propellant combinations.

The contractor will conduct tests on inert grain-sample combinations typical of products produced by several propellant manufacturers. These samples will be prepared with voids between the case and liner and between the liner and propellant. Other samples will be prepared with faults in the solid fuel. Tests will be performed utilizing two basic ultrasonic techniques: (1) the conventional pulse-echo method using one transducer, and (2) a pitch-catch system using two similar transducers, one to send and one to receive.

A special double-yoke crystal probe positioner will be fabricated so that the send/receive method can be evaluated using various incident and reflected beam angles. Special high-energy and low-frequency crystals will be

developed to penetrate the various plies of material. The basic ultrasonic instrumentation for the study will consist of the paper recording system, Immerscope, and one additional sonic set with frequency range down to 0.2 mc. The combination of equipment makes possible a wide range of frequency, energy levels, and presentations.

The majority of the tests will be performed at room temperature (70°F). Some additional tests will be conducted at 50, 32 and 0°F to facilitate ultrasonic transmission through the liner and propellant materials.

DEVELOPMENT AND EVALUATION OF NONDESTRUCTIVE TECHNIQUES FOR ANALYSIS OF SOLID FUEL ROCKETS

Gross, G. L.; McKown, R. D.
December 15, 1959
Ultrasonic Research Lab, Western Reserve University, Cleveland, Ohio
Progress Report 3, October 1–December 1, 1959, 11 pp, SPIA File No. S60-1075, AF 33(616)-6603

The contractor has concentrated mainly upon resolution of defects between the liner and propellant. The results indicate that much more detailed testing is needed to define techniques for this phase of the inspection technique. Samples are being prepared with various case and liner thicknesses, and defect sizes.

An apparatus has been devised to test delamination of the various laminates under conditions of increased compression at the interfaces. A dual crystal manipulator is to be fabricated. Its purpose is to allow for sonic transmission and receipt by two separate crystals, thus reducing near-surface blindness due to crystal ringing.

DEVELOPMENT AND EVALUATION OF NONDESTRUCTIVE TECHNIQUES FOR ANALYSIS OF SOLID FUEL ROCKETS

Gross, G. L.; McKown, R. D.
February 15, 1960
Ultrasonic Research Lab, Western Reserve University, Cleveland, Ohio
Progress Report 4, December 1, 1960, 13 pp, SPIA File No. S60-1076, AF 33(616)-6603

The contractor has sought to resolve the problem of interface pressure conditions between the case and liner materials. Similar tests are under way to determine the results of pressure at the liner/propellant interface. It is believed at this time that compression of the liner/propellant interface would pose a more serious problem than the conditions described in this report.

Several samples of separation of liner and propellant were evaluated in an effort to obtain better resolution of defect size and shape. However, no new progress along these lines has been realized.

A dual-crystal, bottom-swivel manipulator has been completed and is being applied in an attempt to better resolve the liner/propellant interface. Four additional transducers have been obtained to use with the new manipulator—two each crystals of 2.25 and 5.0 mc. These are matched pairs for sending and receiving at the same frequency.

A Branson Sonoray has been purchased and is now being utilized as a low-frequency supplement to the Immerscope. It appears at present that the Sonoray will be particularly useful as a field inspection unit employing the contact technique.

Some effort in the next period will be devoted to the consideration of electronically separating the back reflections from the motor case from the reflections returning from beyond this interface. This investigation was considered worthwhile since the motor case echoes tend to visibly block the information returning from the liner/propellant interface.

MECHANICAL AND THERMAL PROPERTIES OF POLYMERS IN THE SOLID STATE. II. THEORETICAL VISCOELASTIC MODULI AT ULTRASONIC FREQUENCIES

Buvet, R.
***Journal de Chimie Physique*, Vol 57, No. 4, pp 265–275, April 1960 (in French)**

A method of measuring viscoelastic properties at ultrasonic frequencies is described, related to that of Nolle, based on the transmission of short pulses at oblique incidence. The method allows measurements of both compression and shear moduli to be made on the same specimen. The theory is presented together with experimental verification of the validity of the method. The apparatus is fully described.

MECHANICAL AND THERMAL PROPERTIES OF POLYMERS IN THE SOLID STATE. III. VISCOELASTIC PROPERTIES OF SOME POLYMERS AT ULTRASONIC FREQUENCIES

Buvet, R.
***Journal de Chimie Physique*, Vol 57, No. 4, pp 276–286, April 1960, (in French)**

The results of measurements by the method previously described (see preceding abstract) on polymethylmethacrylate, polyhexamethylene adipamide and a polyadipate of pentaerythritol are presented and discussed. In PMMA, no second-order transition could be observed in the curves of wave velocity vs temperature, contrary to recently published results. The shear and compression moduli showed nearly identical behavior with both temperature and frequency. The results on polyhexamethylene adipamide were nonreproducible and interpretation difficult. The polyadipate of pentaerythritol showed high dispersion and indicated nonapplicability of the theory of reduced variables. A molecular theory is presented embracing the different experimental results. The new information claimed to arise from this work is: (1) the existence of compressibility and dispersion of compressibility, providing a link between mechanical and dilatometric properties, and (2) the absence of change of slope in the curves of viscoelastic moduli against temperature, limiting the appearance of a second-order transition to experiments performed statically.

POLARIS POWER PLANT DEVELOPMENT

April 20, 1960
Aerojet-General Corp., Sacramento, Calif.
Report 03520-01M-30, March 1960, Under Patent Secrecy Order, (CONFIDENTIAL)
SPIA File No. S60-560

Ultrasonic inspections revealed that the liner-steel bonds in four first-stage Model A1 motors were not affected by rough-road tests.

ULTRASONICS AND CERAMIC COATINGS

Whymark, R. R.; Lawrie, W. E.
May 1960
Armour Research Foundation, Chicago, Ill.
Progress Report, April 1, 1959–February 29, 1960, 45 pp, WADD TR 60-157, AF 33(616)-6396, ASTIA AD-244,055

This report describes investigations into the use of ultrasonic techniques to determine strength of ceramic/metal bonds and to locate defects in the bonds. The techniques evaluated have involved the use of both high frequencies (1-10 mc), low frequencies (14 kc) and the simultaneous use of high and low frequencies. Experiments at low signal frequencies indicate the average bond strength of flame-sprayed zirconium oxide to be about 1500 psi. Promising results have been obtained using high-frequency transmitted energy and a schlieren detection system. Apparatus is designed to generate surface acoustic waves. The application of surface waves to defect detection is considered. An experimental method has been developed to utilize intermodulation between high- and low-frequency sound waves to indicate bond continuity. Intermodulation techniques obviate the need for repeatable coupling of transducers which is required in direct high frequency transmission methods. Consideration is given to ultrasonic image converter systems.

DEVELOPMENT AND EVALUATION OF NONDESTRUCTIVE TECHNIQUES FOR ANALYSIS OF SOLID FUEL ROCKETS

Ramsey, J. B.; McKown, R. D.
May 15, 1960
Ultrasonic and Research Lab, Western Reserve University, Cleveland, Ohio
Progress Report 5, February 1–May 1, 1960, 30 pp
AF 33(616)-6603, SPIA File No. S60-1077

The contractor has sought to resolve the problem of interface pressure conditions between the propellant and liner. Discussion with solid-propellant rocket manufacturers have established that considerable quantities of moisture are released during the curing of the propellant grain, with the resultant possibility of this moisture being entrapped between interfaces of case/liner and liner/propellant.

The ability of ultrasonics to penetrate various combinations of material and the attenuation characteristics of liner and propellant materials was investigated. Further investigation using low-frequency, high-energy transducers is planned for this area.

The dual-crystal, bottom-swivel manipulator was used to investigate the possibility of detecting liner/propellant bond conditions and appears quite promising. Additional investigations are being conducted to determine the effects and sensitivity of transducer angle, collimation, various transmitter/receiver frequency combinations, and liner thickness, which may be resolved by this technique.

The contact method was investigated using single crystal technique and two transducer technique. Further investigation is being conducted similar to that mentioned previously for the dual-crystal, bottom-swivel manipulator, except that various lucite wedges will be used.

ULTRASONIC INSPECTION OF STUB SKIRT WELD AREAS
Cantor, B. R.; Hart, S. D.
July 26, 1960
Naval Research Lab, Washington, D.C.
TM-132

Nondestructive test procedures which were being employed to inspect stub skirt welds are reviewed. Specific purpose of the review was to determine the feasibility of applying an ultrasonic test as an independent or auxiliary method for the detection of such cracks. Results of the ultrasonic test were tabulated and compared with X-rays which had previously been taken from two directions, namely 5 deg and 15 deg exposure, but were considered well defined in the 15 deg exposure. Typical ultrasonic responses to the flaws in KFI 54 are sketched in this report, and recommendations are made concerning the application of ultrasonic testing for examination of these welds.

REPORT TO SP 271 ON ULTRASONIC INSPECTIONS OF SHEET STEEL
Hart, S.
October 10, 1960
Naval Research Lab, Washington, D.C.
TM-141

C. Miscellaneous

SERVICEABILITY OF OVERAGE ROCKET MOTOR, M58 [U]
Jennens, P. P.
March 1960
Ogden Air Materiel, Hill Air Force Base, Utah
Report OOY TR 60-5, 30 pp, (CONFIDENTIAL)
ASTIA AD 317,002

A test was conducted to determine if the overage (40- to 41-month old) M58 rocket motors could be utilized for limited use in training. The motors were drawn from Air Force inventory as the oldest available motors. The motors were inspected visually and by X-ray. Results of visual and X-ray inspections showed no adverse conditions. They were static fired at −10°F to record the thrust vs time results. The performance was within the acceptance limits for thrust, total impulse, and burning time. It was concluded that the motors up to the age of 40 months were safe and reliable, providing they were handled normally and were fired between 0 and 150°F.

USING SCALE ROCKET MOTOR PERFORMANCE AS A BASIS FOR THE ACCEPTANCE OF LARGE ROCKET MOTORS
Sola, F. L.; Hylton, J. C.
March 16, 1960
Jet Propulsion Lab, Pasadena, Calif.
Publication 174, (CONFIDENTIAL)

An acceptance specification has been developed which utilizes the conventional inspection techniques for motor hardware, loading fixtures, and propellant and liner physical properties, as well as the finished rocket motors, thus reducing the probability of accepting rocket motors which may fail due to structural or propellant physical defects. In addition, the requirement that the ballistic performance of a finished rocket motor be accurately predicted within fixed values over a wide temperature range is fulfilled by use of scaled replicas of the full-size rocket motor.

REPORT ON NON-DESTRUCTIVE TEST METHODS USED ON *POLARIS* CHAMBERS AND CLOSURES
Cantor, R.
March 30, 1960
Naval Research Lab, Washington, D.C.
TM-115

Answers to a questionnaire distributed to fabricators on *Polaris* chambers and closures as to methods employed in nondestructive tests of these parts are summarized and analyzed. Recommendations for improvement of techniques are made where needed.

SOLID PROPELLANT AGING STUDIES
Beyer, R. B.; Fishman, N.
June 24, 1960
Stanford Research Institute, Menlo Park, Calif.
Report 25, QPR 9, March 31–June 30, 1960
AF 33(616)–5806, SPIA File No. S60–965

The ultimate objectives of this program are to develop information which would lead to an ability to predict the serviceable life of operationally deployed rocket motors and to develop nondestructive techniques for determining the aging of such motors. This report includes discussion of experimental results, the status of technique development, and plans for the forthcoming storage program.

The storage program plan being formulated provides for aging most of the propellant samples in ovens at the

Institute's remote site, with small-scale surveillance at Menlo Park. Time periods will be determined by results of the small-scale program, which will be conducted almost exclusively with nondestructive evaluation methods. Primary evaluation will be made by creep stress relaxation, and low-temperature high-rate tensile measurements, with added correlative tests in which various nondestructive and chemical methods will be used.

Low-temperature high-rate tensile measurements on samples of ANP-512-DS Mod III showed that this propellant exhibited transition behavior at rates of 100 to 300 in./in.-min in the temperature range of 0 to −20°F.

Chemical studies of a polyurethane system consisted of development of procedures for making the elastomer and of some investigations into degradation mechanism. Polyurethane resins were prepared for continuing investigations of the sonic transmission/attenuation technique. A sonic cell was cast in place in a polyurethane resin, and the cure and subsequent degradation, as measured by changes in transmittance, were successfully monitored.

Considerable modification of instrumentation was undertaken to enable recording of most test data with an optical oscillograph. The new square-cross-section test specimen and accompanying gripping jaws were tested, with satisfactory results. Other technique development efforts in progress include measurement of dielectric properties and study of creep behavior under a superimposed sinusoidal oscillation.

A RESEARCH STUDY TO ADVANCE THE STATE-OF-THE-ART OF SOLID PROPELLANT GRAIN DESIGN
Jones, H. G.
July 18, 1960
Thiokol Chemical Corp., Elkton Division, Md.
QPR 4, February 1–May 1, 1960, 28 pp
AF 33(616)-6530, ASTIA AD-243,708
(see also AD-233,296, AD-240,146, AD-314,298)

Two changes were incorporated into the detailed IBM 650 computer program for the slotted grain configuration. The first change enabled the detection of the phenomenon where one section, or slug, of propellant might burn out of the grain, allowing it to be free within the combustion chamber and to plug the nozzle and cause engine malfunction. The second change increased the versatility of the program by allowing the prediction in advance of all possible sequences of disappearance of burning surface perimeters.

Feasibility studies are being made of the photo-stress method for analysis of the propellant grains. The photo-stress method is a photoelastic stress analysis technique where the structure to be stress analyzed is coated with a transparent plastic, a load is applied, and strains are transmitted to the coating which becomes birefringent. The birefringence is directly proportional to the intensity of strain. Photo-stress results obtained for tests where the grain was subjected to a steady uniform internal pressure and an external rigid case indicated that strains are nonexistent within a propellant whose Poisson's ratio is 0.5. Results obtained from the thermal testing of the propellant grain by temperature cycling of the system from 155 to 30°F definitely indicated strain distributions compatible with changes in temperature.

BULLETIN OF THE JOINT MEETING JANAF PANELS ON PHYSICAL PROPERTIES AND SURVEILLANCE OF SOLID PROPELLANTS HELD AT THE ATLANTIC RESEARCH CORPORATION, ALEXANDRIA, VIRGINIA, SEPTEMBER 20–22, 1960
Solid Propellant Information Agency,
Silver Spring, Md.
Publication PP-13 and Publication SPSP-8,
August 1960, NORd-7386 (CONFIDENTIAL)
ASTIA AD-320,088

SOLID PROPELLANT AGING STUDIES(U)
Beyer, R. B.; Fishman, N.; White, B. B.
October 10, 1960
Stanford Research Institute, Menlo Park, Calif.
QPR 10, June30–September 30, 1960, 63 pp
AF 33(616)-5806 (CONFIDENTIAL)
ASTIA AD 319,983

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